A COMPARATIVE STUDY ON LAMINAR FLOW OF MULTIPLE ORIFICE GASES THROUGH A TUBULAR WELDING ELECTRODE

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ABSTRACT

For an attempt to design a recently developed environmentally friendly manual welding process, that is aimed at reducing/eliminating the use of cellulose in its flux coating, a tubular coated welding electrode with a gas passes through the orifice of the tube is necessary. The objective of this study is to investigate and understand the flow characteristics of such intended orifice gasses that are to flow through the electrode tube. An attempt was made to simulate the flow of three different gasses such, argon, helium and carbon dioxide by using a commercial finite element tool with volumetric flow, mean velocity and pressure head as input parameters. A specially made mild steel coated electrode tube with an inner diameter of 1.8 mm was considered for the study. An axisymmetric mode was generated based on the tubular welding electrode dimension with inlet,pipe wall,center line and outlet as boundary regions.The model was simulated with optimum mesh grid size on axial and radial distance of the axisymmetric model. From the result obtained the fluid flow characteristic such as laminar,transition and turbulent were found at selected volume flow rate ranges. The characteristic of fluid flow regions and the relationship of entrance length, pressure variation and maximum velocity at fully developed region were obtained. The simulated results were compared and validated with analytical solutions for the accuracy.

***KEYWORDS**: Shielded metal arc welding; computational fluid dynamic; internal flow; entrance length; laminar flow; reynolds number*

1.0 INTRODUCTION

Engineering fabrication by using welding is a prevalent process which is considered to be environmentally unfriendly due to the fact that it uses chemicals for its flux coating over the metal surface which exhausts toxic gasses and metal vapor to the atmosphere during welding (Wang

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et al., 2003; Jeefus, 2012). There have been several attempts hence, to make the process towards self-sustainability and more environmentally friendly. Tubular welding technique (Pandey, 1999), a modified version of conventional Shielded metal arc welding (SMAW) process is one of such attempts aimed to reduce/eliminate the organic cellulose from the flux coating of cellulose electrode (EXX10) which are pre dominantly used in pipeline welding.

The tubular welding technique showed in Figure 1(a) uses an auxiliary gas flow to increase the transfer rate of molten metal into weldments, which plays a major role to produce a higher weld penetration. Mild steel tube was used as electrode material and coated with a rutile coating that helps to generate the required shield for the weldment from atmosphere (Pandey et al., 2003).

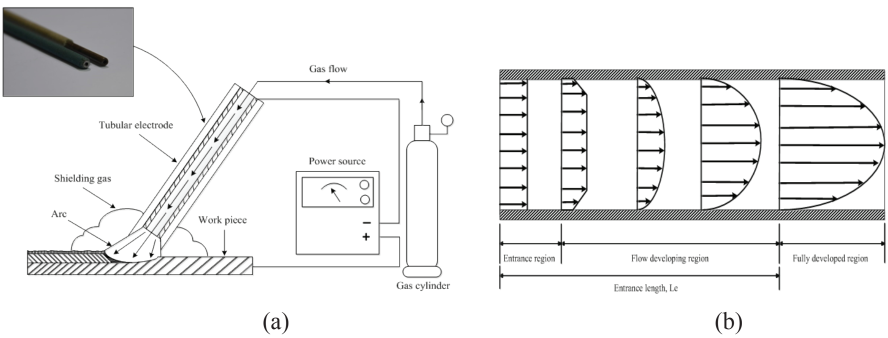


Figure 1. (a) Tubular welding technique and (b) internal flow characteristic in the tube

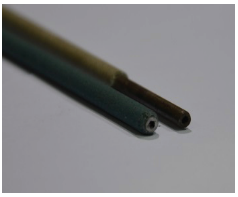
There are three types of flow generally observed in a fluid flow such laminar, transition and turbulent (Cengel & Cimbala, 2006). By definition, laminar flow has smooth streamlines and high ordered motion, where as transition flow occurs in a region where the flow fluctuated between laminar and turbulent before becoming fully developed turbulent flow. Turbulent flow is a disordered motion of fluid with high velocity fluctuations. The fluid flow generally depends on flow velocity, type of fluid, surface roughness and surface temperature (Merle & David, 2002). Figure 1(b) shows the internal flow characteristic in the tube where, the flow in the entrance region is known as hydro dynamically developing flow where in this region the velocity profile develops and the region beyond the entrance region in which the velocity profile is fully developed and remains unchanged is known as hydro dynamically fully developed region (Merle & David, 2002). The velocity profile in the fully developed region is parabolic in laminar flow and somewhat flatter (or fuller) in turbulent flow due to eddy motion and more vigorous mixing in the radial direction (Cengel & Cimbala, 2006). It was reported (Pandey et al., 2003) that the unitary gas was set to be laminar flow with a pre-determined range of flow rate make metallurgically sound weld bead with high penetration. However there have been very limited or no publication on the true behavior of unitary/multiple gases when flow at laminar flow through the tubular electrode. This paper presents an investigation on the fluid flow analysis by computational fluid dyanamic method (CFD) simulation to predict and study the fluid flow characteristic of multiple orifice gases in the tubular welding electrode. Three types is orifice gases were applied for the simulation such argon, helium and carbon dioxide with selected volume flow rate as input variables. The fluid flow development regions were studied and the maximum velocity at fully developed region was obtained on each gases. The simulation results were validate with theoretical method for an accuracy measurement.

2.0 A COMPUTATIONAL FLUID DYNAMIC ANALYSIS IN THE INTERNAL FLOW

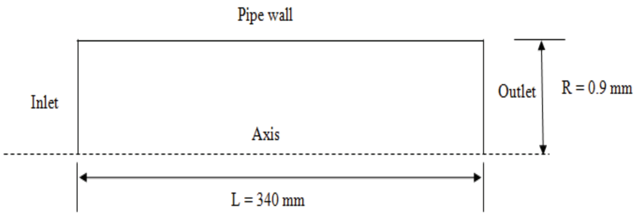
From the recent studies on modeling and simulation of laminar fluid flow characteristics and measurement are concerned with the macro dimensional scale. Details of such studies can be found in (Peng & Conte, 2008; Farhan & Abbas, 2011; Yao et al., 2013). The importance of meshing grid size in achieving greater accuracy in prediction of flow characteristics was also widely reported by (Wensheng et al.,2006) studied the entrance length flow simulation using various meshing sizes (grid size) at a circular pipe in laminar and turbulent flow. The compared results of single and multi grids with various mesh grid size on axial and radial distance of circular pipe showed that the multi grid produced a least computation time and a reasonably accurate prediction of fully developed laminar and turbulent flow characteristics. (Prashant et al., 2010) reported a similar conclusion from his numerical study with variety of mesh grid sizes on laminar flow entrance length in a straight circular a pipe. The prediction of entrance length was carried out by employing Computational Fluid Dynamic (CFD) Fluent V6.2 with a 2D axisymmetric model being applied under incompressible flow conditions. (Molki et al., 2013) studied and measured the velocity profile gradient at fully developed region of a horizontal transparent pipe under laminar flow condition by using a Laser Doppler Velocimeter (LDV). For the present work the centerline maximum velocity of the parabolic laminar flow was considered as two times of an average velocity at the fully developed region.

3.0 PLAN OF INVESTIGATION

The tubular electrode which was manufactured in specific dimensions of 1.8 mm internal diameter, 4.0 mm outer diameter and tube length 340mm as shown in Figure 2 (a) was considered for the study .The investigation of flow characteristic was carried out with three stages, the first stage was to set the control variable which influence the flow characteristic such volume flow rate, velocity inlet, and types of shielding gases such argon, helium and carbon dioxide gases.



(a)



(b)

Figure 2. (a) Manufactured tubular welding electrode and (b) Schematic diagram of tubular welding Electrode with boundary region/ condition in axisymmetric geometry

The second stage was to generate the tubular model by employing ANSYS fluent (Version 14) and the model was tested with input variable and different types of shielding gases. In this stage, the model was generated in axisymmetric geometry and boundary conditions of tube were taken in account. The boundary conditions are summarized schematically in Figure 2(b). The model was then simulated for different flow conditions. Simultaneously, by applying standard theoretical formulae, the velocity gradients at various phases of flow inside the tube and the corresponding Reynolds numbers were calculated analytically. The third stage of this work was to compare, interpret and analyze the results obtained from simulation and analytical methods in graphical form.

4.0 DETERMINATION OF FLOW CHARACTERISTICS THROUGH THE TUBULAR ELECTRODE

By standard fluid mechanics principles, the general equation of volume flow rate in horizontal pipe is given by,

$$Q = AV \quad \text{or} \quad Q = \frac{\Delta P \pi D^4}{128 \mu L} \tag{1}$$

where Q is the volume flow rate in m^3/s, "A" represents tube area in m^2 (2.54e-06 m^2) and V is velocity of inlet in m/s. The velocity inlet in the tube was considered to be the average velocity when the velocity at the tube wall was considered to be at 0 m/s. It was reported from the previous work (Molki et al., 2013) that the mean velocity inlet was considered in a rectangular duct flow. The inlet average velocity (Merle and David, 2002; Cengel & Cimbala, 2006) is given by,

$$V_{in\ avg} = \frac{\Delta P D^2}{32\mu L} \tag{2}$$

also, the Reynolds number that characterizes the fluid flow type in a tube, based on the stipulated conditions of 2300 > Re > 4000 (Cengel & Cimbala, 2006; Molki et al., 2013) is represented as,

$$R_e = \frac{\rho . V_{avg} . D}{\mu} \tag{3}$$

Gas densities, argon (1.6228 kg/m^3), helium (0.1625 kg/m^3) and carbon dioxide (1.7878 kg/m^3) with viscosities of argon (2.125e-05 kg/ms), helium (1.99e-05 kg/ms) and carbon dioxide (1.37e-05 kg/ms) (Ramsey et al., 2012; Cengel & Cimbala, 2006) were considered for calculations respectively. For pressure distribution from inlet and outlet of the tube, the equation is given by

$$\Delta P = \frac{32\mu L . V_{avg}}{D^2} \tag{4}$$

For the measurement of pressure loss (*Pa*), viscosity μ (of each gases in kg/m.s), an average velocity (m/s), the model diameter, D is 1.8 mm and tube length L, 340 mm (Cengel & Cimbala,2006; Wensheng et al.,2006; Peng & Conte, 2008) were considered. The entrance length L_e of the fluid flow in the internal flow was calculated by applying a standard formula of fluid mechanic (Cengel & Cimbala,2006) is given by,

$$L_e = 0.06 . R_e . D \tag{5}$$

Where the entrance length is proportional to the rate of Reynold number of the fluid flow (Merle & David, 2002; Elsiby et.al.,2011). The data generated was based on analytical method in order to identify the flow characteristic in the tubular electrode. The range of volume flow rate Q, in this study was kept at 0.5, 0.8, 1.1, 1.4, 1.7 and 2.0 L/

min. Table 1, 2 and 3 shows the tabulated data for each shielding gases generated using standard formula as mentioned in equations (1) to (5). The simulation results were obtained where the velocity profile, generated at the fully developed region and the velocity at outlet varied with volumetric flow rate as input variables with division grid size at axial and radial edge on model is 1200 x 11 equal to 13200 elements and 14412 nodes. The simulation work graphical illustration of fluid flow in a tube was generated as shown in Figure 4 and the illustration clearly indicated that the flow developing in the entrance region and become fully developed after entrance length till end of tube.

Table 1. The calculated input control variables and the resulted flow characteristics for Argon gas

Volume flow rate, Q (L/min)	**Velocity inlet, V_{avg} (m/s)**	**P_2-P_1 (ΔP) (Pa)**	**Reynolds number (R_e)**	**Entrance Length (mm)**	**Flow region (FD-Fully developed)**	**Flow Characteristic**
0.5	3.27	233	450	48.61	FD	Laminar
0.8	5.23	373	720	77.77	FD	Laminar
1.1	7.20	514	990	106.94	FD	Laminar
1.4	9.16	654	1260	136.10	FD	Laminar
1.7	11.13	794	1530	165.27	FD	Laminar
2.0	13.09	934	1800	194.44	FD	Laminar

Table 2. The calculated input control variables and the resulted flow characteristics for Helium gas

Volume flow rate, Q (L/min)	**Velocity inlet, V_{avg} (m/s)**	**P_2-P_1 (ΔP) (Pa)**	**Reynolds number (R_e)**	**Entrance Length (mm)**	**Flow region (FD-Fully developed)**	**Flow Characteristic**
0.5	3.27	218	48	5.184	FD	Laminar
0.8	5.23	350	77	8.316	FD	Laminar
1.1	7.20	481	105	11.34	FD	Laminar
1.4	9.16	612	134	14.472	FD	Laminar
1.7	11.13	743	163	17.604	FD	Laminar
2.0	13.09	875	192	20.736	FD	Laminar

Table 3. The calculated input control variables and the resulted flow characteristics for Carbon dioxide gas(CO2)

Volume flow rate, Q (L/min)	Velocity inlet, V_{avg} (m/s)	P_2-P_1 (ΔP) (Pa)	Reynolds number (R_e)	Entrance Length (mm)	Flow region (FD-Fully developed)	Flow Characteristic
0.5	3.27	150	769	83.052	FD	Laminar
0.8	5.23	241	1230	132.84	FD	Laminar
1.1	7.20	331	1692	182.736	FD	Laminar
1.4	9.16	421	2153	232.524	FD	Laminar
1.7	11.13	512	2615	282.42	-	Transition
2.0	13.09	602	3076	332.208	-	Transition

5.0 CFD SIMULATION ON THE AXISYMMETRIC MODEL

The simulation on the axisymmetric model was carried out by following the five standard stages of procedure such as geometry, meshing, setup physics, solution and result (Darus, 2000; Venkata et al., 2012; Devi et al., 2011). Firstly at the pre-processsing procedure the simulation model was generated with 2D axisymmetric geometry with dimension as shown in Figure 2(b), then model was meshed with several consideration, first the model meshed mapped face meshing option then edge sizing was applied on the axial and radial edges with mesh grid division and model behavior. Then on the each boundary region the name selection was applied by named the region such inlet, outlet, symmetry and wall. As the second procedure the selection of boundary condition and solver were applied on the meshed model. In this steps the selection of solver types, and processing option, velocity formulation, time, 2D space: axisymmetric were applied . In the boundary condition for separate analysis each fluid medium was applied such Ar, He and CO_2 and the flow channel body was selected as mild steel material. The Input variables as show in Table 1-3 are applied accordingly in the boundary region on inlet, centerline, wall and outlet. In the solution option selection of analysis input was applied such solution control, monitors, solution initialization method before the final run analysis with literation input. Thirdly as final procedure or known as post–processing, the result of the fluid flow in the axisymetric model was recorded. The result such contour and vector plot, velocity inlet, outlet, maximum velocity at center line and outlet boundary and pressure distribution at center line, wall and outlet boundary condition were record accordingly on each analysis runs. The outlet velocity and pressure data at the selected boundary region were extracted for each gases for further graph plotting. Then the obtained results were used for validation with establish theoretical result.

6.0 RESULTS AND DISCUSSIONS

Based on the obtained resuts , the volume flow rate was used as main input variable and simulated with three different shielding gases such as argon, helium and carbon dioxide. From the selected volume flow rate range, it was found that the velocity inlet becomes a major factor on determining the flow pattern in the 1.8 mm tube diameter axisymetric model. From the calculated input data as shown in Table 1-3 , the fluid flow in the axisymmetric model was identified as laminar flow for all three gases such Ar, He and CO_2 and when the volume flow rate equal and exceeded at 1.7 l/min at CO_2 the flow starts to flowing in a transition flow pattern. The transformation of flow pattern from laminar to transition in carbon dioxide gas is due to the effect of gas property, which CO_2 has a high density (1.7878 kg/m^3) as compared to argon (1.6228 kg/m^3) and helium (0.1625 kg/m^3). From these three gases it was found that the pressure difference (ΔP) was increased proportionally to the increment of volume flow rate (Q), which was recorded higher at Argon followed by Helium and Carbon dioxide gas. The pressure distribution (ΔP) clearly shows the influenced by the flow rate , where volume flow rate and pressure in the flow channel are both related each other (Farhan & Abbas, 2011). In addition other factors that influences the changes of pressure difference in the flow model such viscosity (μ), velocity inlet (V_{avg}) and geometry of flow channel such diameter and tube length (D and L). The effect of Reynolds number (Re) are clearly observed for each simulation at Ar, He and CO_2 on internal flow. The factors influences for *Re* such gas density,viscosity, flow channel diameter and input velocity. The fluid flow was simulated from the input data as shown Table 1-3 and the final simulation result are shown in Table 4-6.

Table 4. The simulation result for argon

Q	$U_{in, cfd}$	$V_{out, cfd}$	$V_{max, cfd}$ (at fully developed region)	$Re_{, cfd}$ (at fully developed region)	Flow Characteristic
0.5	3.27	3.22	6.44	885	Laminar
0.8	5.23	5.04	10.08	1385	Laminar
1.1	7.20	6.74	13.48	1852	Laminar
1.4	9.16	8.31	16.62	2284	Laminar
1.7	11.13	9.81	19.62	2696	Transition
2.0	13.09	11.23	22.46	3087	Transition

Table 5. The simulation result for helium

Q	$U_{in, cfd}$	$V_{out, cfd}$	$V_{max, cfd}$ (at fully developed region)	$Re_{, cfd}$ (at fully developed region)	Flow Characteristic
0.5	3.27	3.25	6.5	95	Laminar
0.8	5.23	5.19	10.38	152	Laminar
1.1	7.20	7.15	14.30	210	Laminar
1.4	9.16	9.10	18.20	267	Laminar
1.7	11.13	11.04	22.08	324	Laminar
2.0	13.09	12.99	25.98	381	Laminar

Table 6. The simulation result for carbon dioxide

Q	$U_{in,\ cfd}$	$V_{out,\ cfd}$	$V_{max,\ cfd}$ ***(at fully developed region)***	$Re_{,\ cfd}$ ***(at fully developed region)***	**Flow Characteristic**
0.5	3.27	3.14	6.28	1475	Laminar
0.8	5.23	4.76	9.52	2236	Laminar
1.1	7.20	6.24	12.48	2931	Transition
1.4	9.16	7.62	15.24	3579	Transition
1.7	11.13	9.43	18.86	4430	Turbulent
2.0	13.09	10.21	20.42	4796	Turbulent

From the obtained result as shown in Table 4 till 6, if was found that the helium gas recorded as laminar flow characteristc on all selected volume flow rate range at 0.5 till 2.0 l/min.

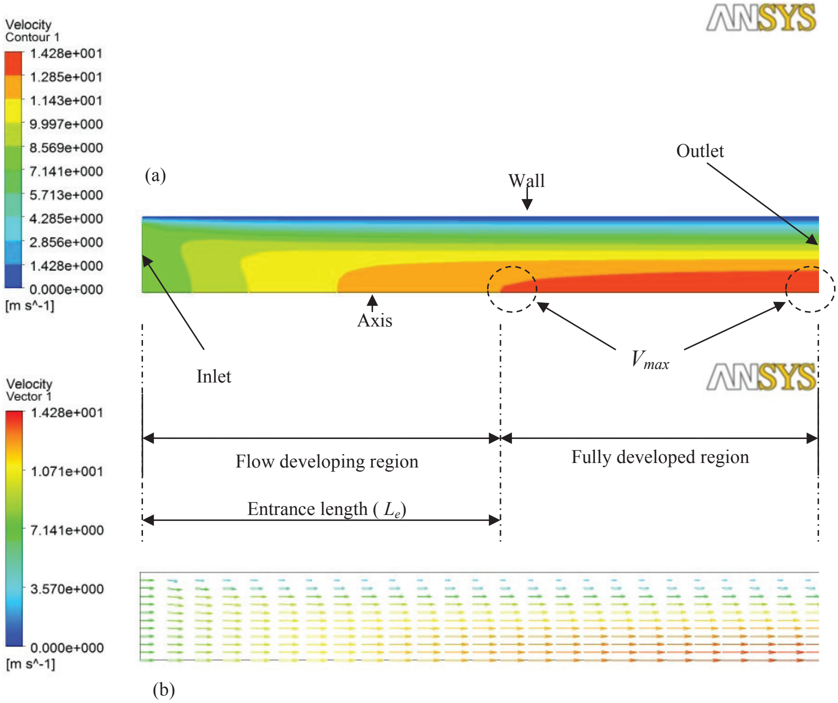


Figure 3. The simulation contour (a) and vector (b) illustration of fluid flow in the 1.8 mm tubular welding electrode in axisymmetric orientation.

Figure 3 illustrated the fluid flow in contour image, there are two type of flow region were found which the flow is developing at the entrance region and at the entrance length, *Le* the flow transform as developed and become fully developed flow as shown in Figure 3. The image in Figure 3(a) marked as V_{max} indicating the maximum velocity point in laminar flow which the velocity is zero at the wall and maximum at the axis centreline. Figure 3(b) indicated the illustration of fluid flow in vector form where the arrow direction shows the flow starts in developing at the inlet region and become developed and fully developed at the pipe outlet. Moreover, the developing region also called as hydrodynamic entrance region, based on the velocity profile obtained from the simulation the pattern of development characteristic are different on each range of volume flow rate and shielding gases due to the effect of boundary layer. In this region the effect of gas viscosity is the major influence due the present of viscous shearing force. The fully developed flow or also known as hydrodynamically fully developed region occurred in the simulation model (axisymmetric) when the thickness of the boundary layer increases in the axial flow direction until at a state when the boundary layer reached and merge with the centre line of the tube of the entire tube. At the gas flow entered and flowing in the inlet region the boundary surface has a characteristic with negligible friction and flowing with constant velocity at radial direction, these state is known as irrotional core flow region in the hydrodynamic entrance region. Another region in hydrodynamic entrance region known as boundary layer region which in this region the viscous effect and velocity effect is very significant occurred , which shown in Figure 4. The optimum range of volume flow on the helium gas at 2.0 l/min was simulated to investigate the entrance length behavior of laminar flow as shown in Figure 4 and 5. From the scatter line graph as shown in Figure 4, it was found that the fluid flow on the selected volume flow rate is flowed with two stages of fluid flow region such as developing flow and fully developed flow region .

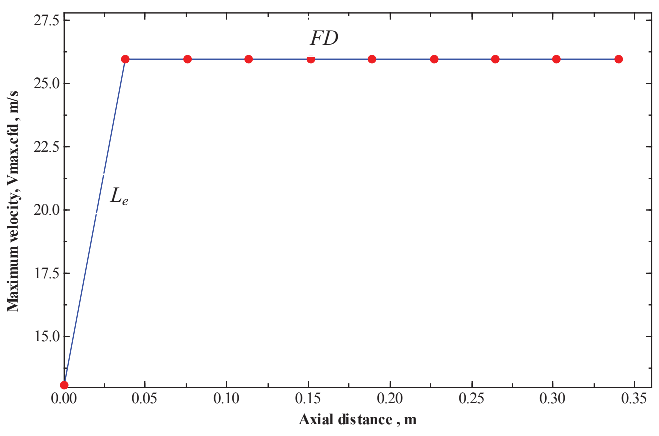


Figure 4. The entrance length development on the axisymnetric model at Q = 2.0 l/min of Helium gas

In this region the velocity of fluid is gradually increased till the optimum velocity rate (known as entrance length distance, *Le*) before flowing with constant and maximum velocity known as developed flow. The velocity contour image as shown in Figure 5 illustrated that the flow development at the entrance region , L_e with color indication (green/ yellow/orange) and the flow start to be fully developed flow , *FD* with constant flow onwards as indicated in red color which reflecting the similar relationship of fluid flow characterisctic is shown in Figure 4 .In addition on Figure 4 the Helium gas flowing at initial velocity inlet at 13.09 m/s till the maximum velocity at 25.98 m/s then flowed with constant speed at fully developed region (FD) till the end of axial length at 340 mm of axisymmetric model.

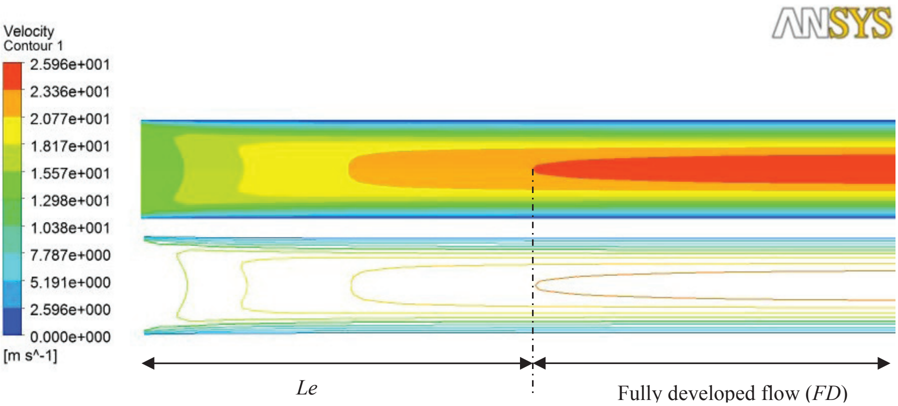


Figure 5. The velocity flow contour image of Helium gas at volume flow rate 2.0 l/min

From the theoretical calculations, the entrance length, L_e as shown in Table 1-3 ,the shielding gases are refecting as direct proportional behavior to the Reynolds number (Cengel & Cimbala, 2006; Venkata et al., 2012). The entrance length (L_e) is varied on each the selected volume flow rate and orifice gases as shown in Table 1-3. These variation of L_e occurred due to the effect of gas property, where the fluid density on each gases has it own atom weights and travel speed. The result obtained proved that the helium gas with a lowest density properties travel with fastest with shortest developing length as shown in Table 2. Figure 6 shows the pressure distribution and relationship along the axial length of the simulation model. The graph plotted at varies type on gases and range of volume flow rate, *Q* on the optimum laminar characteristic on the result as in Table 4-6.The Pressure varies on the volume flow rate, which the volume flow rate direct proportional to the pressure distribution in the internal flow channel (Cengel & Cimbala, 2006; Molki et al., 2013). In addition the pressure is higher at inlet boundary wall and the pressure gradually drop due to the effect of flow development from developing region into the fully developed region. At the tube distance of 340 mm , the pressure at the wall is dropped into the minimum level which is zero as found from the simulation. According to the theory of laminar flow profile, the velocity is maximum at centre and zero at the wall and for pressure distrubution, the pressure is maximum at the wall and zero at centreline of the with fully parabolic shape (Cengel & Cimbala, 2006; Merle & David, 2002). From the simulation it was found that maximum velocity was orientated at the centerline with zero pressure rate and the pressure is maximum at the axisymmetric model wall with zero velocity respectively, thus the obtained result is tally with the establish fluid mechanic laminar flow law (Cengel & Cimbala, 2006).

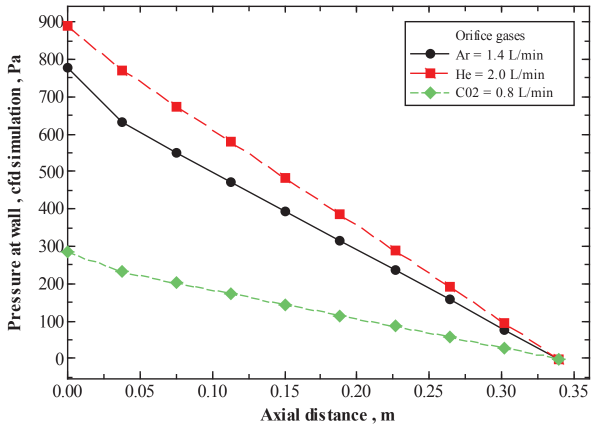


Figure 6. Pressure variation at the wall boundary on the axial distance (340 mm) of the simulation model in the Laminar flow.

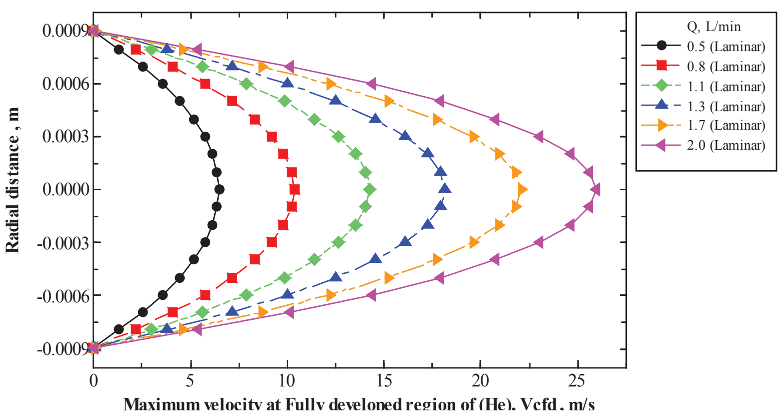


Figure 7. Velocity profile of maximum velocity of Helium gas at outlet boundary region with varies range of volume flow rate,Q (L/min).

The maximum velocity, CFD at outlet region as shown in Table 4 till 6 were used for plotting the velocity profile as shown in Figure 7 till 9. The velocity velocity profile plotted on selected volume flow rate range 0.5 till 2.0 for each orifice gases. From the velocity profile it was found that the parabolic shape of flow pattern are differ on each orifice gases and volume flow rate ranges. Moreover it was found the helium gas travel in high velocity followed by argon and carbon dioxide gas. The gas properties such density (ϱ) and viscosity (μ) played role for fluid flow in gas speed compared to other volume flow rate effect .The lighter gas density able to travel faster compared to heaver gas density (Pandey, 1999).

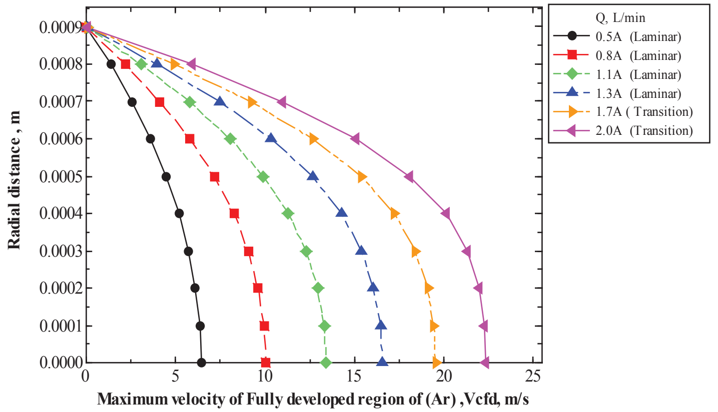


Figure 8. Velocity profile of maximum velocity of Argon gas at outlet boundary region with varies range of volume flow rate,Q (L/min).

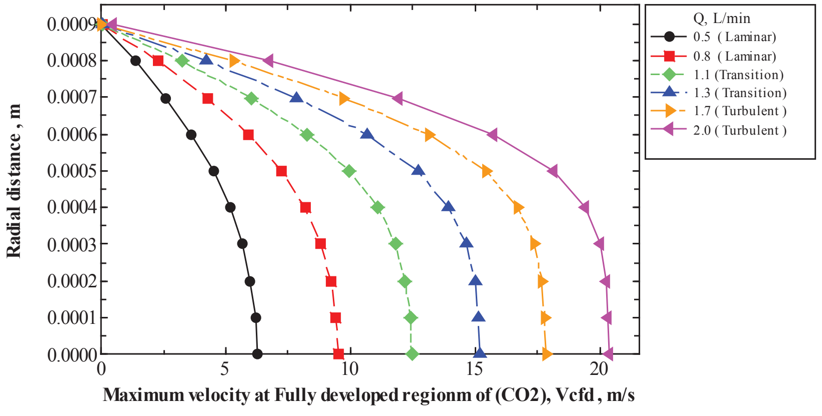


Figure 9. Velocity profile of maximum velocity of Carbon dioxide gas at outlet boundary region with varies range of volume flow rate, Q (L/min).

Three major flow patterns were found such such laminar, transition and turbulent. As shown in Figure 7-9 the velocity profile in the fully developed region is parabolic shape for laminar flow and flatter (*fuller*) for turbulent flow due to the eddy motion and has a vigorous mixing in the radial direction in the axisymmetric model.

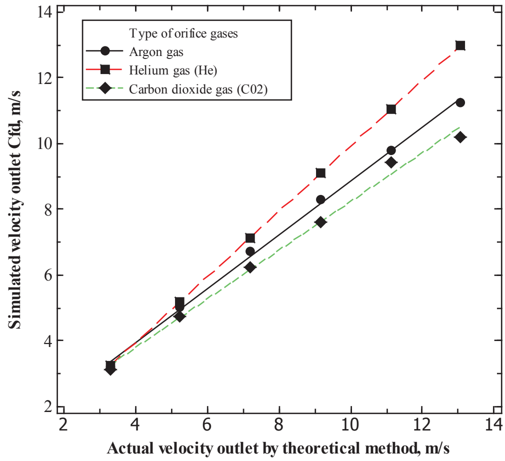


Figure 10. Validation of CFD Simulation with analytical result of velocity outlet (V_{out}) fluid flow analysis on the 1.8 mm diameter of axisymmetrical model.

The result from CFD simulation were validated with theoretical method, it was found that the simulated result more closer to the actual result as shown in Figure 10. The validation was made with theoretical and simulation value of velocity outlet for selected volume flow rate at 0.5 till 2.0 l/min in three multi orifice gases (Ar, He and CO_2). From the validation result, the Helium gas was recorded 0.6 (%) percentage of error compared to argon and carbon dioxide gas as show in Figure 10. Further mesh refinement could be implemented to get a closer simulation results as compared to the analytical results in the axisymmetric model in this study.

7.0 CONCLUSIONS

The following conclusions are drawn from the study.

a) An axis-symmetric tubular weld electrode tube model was developed to predict the flow characteristic of three orifice gases such as argon, helium and carbon dioxide in a range of volume flow rates. Three types of fluid flow characteristics were found such laminar, transition and turbulent. The fluid flow characteristics are varied with the increament of Reynolds number which is affected by the the volume flowrate and velocity inlet in the model.

b) The entrance length, pressure variation on the wall boundary and the maximum velocity at the outlet boundary region are influenced by the input variables such volume flow rate and properties of each gases.

c) The laminar flow development shows that the flow is developed gradually at developing region and flowed with constant velocity speed as fully developed flow till the outlet boundary region.

d) The development of entrance length is varied on each gases. Helium gas recorded with a fastest flow development , which the fluid flow travels with a short distance of *Le* before the flow transforms to fully developed flow in the model. This effect due to the influence of gas properties which the helium has a lowest density compared with argon and carbon dioxide gas.

e) From the CFD simulation at the fully developed region ,it was found that helium gas flowed with fully developed laminar flow at the volume flow rate range 0.5 till 2.0 l/min compared with Argon and carbon dioxide gas. The fluid flow characteristic in developing and fully developed region are clearly observed from simulation and theoretical method in the axisymetric model.

f) The simulated values are compared to the measured values determined by standard formulae and both the simulated and measured values are in good agreement with 0.6 percentage of error and the results could be improved further by mesh refinement to enhance the validity and accuracy.

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